Teak Clonal Forestry

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As anticipated more than two decades ago (Monteuuis 1995, Monteuuis and Goh 1999, Goh and Monteuuis 2005), teak clonal forestry has now become a reality. Teak clonal plantations have rapidly expanded over the past years, mainly under the impulse of private investors driven by financial interests. Access to information is as such limited and therefore this report should not be considered as exhaustive and definitive, but more as a broad presentation of teak clonal forestry to date.

Rationale for developing teak clonal plantations

Propagation by seeds remains for teak as for many other tree species, the easier and more natural and efficient way to produce offspring. These are all genetically different from one another. This is essential for the maintenance of genetic diversity and also for genetic improvement. Propagating teak through seeds has been practiced for centuries, with the possibility of storing the seedlings in the form of "stumps" when necessary, for instance while waiting for suitable planting conditions (Monteuuis and Ugalde 2013). However, mass production of teak planting stock by seeds is hindered by serious handicaps such as:

i) A negative correlation between the onset of fruiting/seed production and clear bole length affecting the commercial value of the latter (Callister 2013). Practically, seeds collected from early flowering individuals will ultimately give rise to poor quality and short-bole trees.

ii) quantitatively limited seed production that is prone to between tree, year and site variations.

iii) low and unpredictable seed germination capacity that rapidly declines with time after collection, although differences may exist between seed sources (White 1991).

iv) noticeable variability among individuals, even when derived from the same mother tree, affecting traits of major economic importance like growth, trunk form, branchiness, technological and aesthetic wood characteristics (Figure 1, Bedel 1989, Chaix et al 2011, Monteuuis et al 2011).

v) Insufficient inheritance of economically significant traits making the ultimate gain uncertain, notwithstanding the time constraints associated with sound breeding programs (Kjaer and Foster 1996, Chaix et al 2011, Monteuuis et al 2011).

Figure 1: 3.5yr-old seed (left) and clone - derived teaks in Mato Grosso, Brazil

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By contrast, cloning consists in duplicating genotypes, theoretically unlimitedly, by asexual or vegetative propagation methods, while preserving through mitotic divisions their original genetic make-up. Consequently all their characteristics, including those of great economic impact usually poorly inherited by seed propagation, will be transferred to the offspring. The resulting crop will uniformly exhibit all the features of the original tree it arises from. This emphasizes the importance of reliably selecting candidate plus trees, or CPTs, to be cloned. These CPTs must be really outstanding for as many economically important traits as possible (Murillo and Badilla 2002, Goh and Monteuuis 2005, Goh et al 2007). Further, vegetative propagation can be applied to any individual that does not produce fertile seeds, either because it has not entered the mature stage yet, or due to unfavourable environmental conditions.

For teak as for any other tree species, cloning can be useful for research purposes as well as for commercial planting (Monteuuis and Goh 1999). Teak clonal plantations are expected to produce higher yield of greater quality timber than seed-derived ones to get the best and earliest returns on investment. This is crucial for overcoming the tremendous deficit in supply and to meet ever increasing international demands of superior teak wood that can no longer be harvested from natural teak forests. Intensification of crop productivity is also spurred by the increasing demographic pressure on land tenure. Practically, however, the development of teak clonal plantation remains strongly dependent upon the capacity of the species to be efficiently mass clonally propagated.

From theory to practice: the determining breakthrough offered by the possibility to clonally propagate teak Plus trees efficiently

The mass production of teak clones, especially from mature selected trees has for a long time been hindered by the lack of suitable technology. Grafting has been practised for decades but mainly on a small scale for establishing clonal seed orchards or “CSO” in various countries (White 1991, Monteuuis and Ugalde 2013). A few experiments have demonstrated that teak genotypes of various ages could be propagated *in vitro* but not with the efficiency required for mass production (Gupta et al 1980, Mascarenhas and Muralidharan 1993). The situation changed dramatically during the 1990s with the development of efficient nursery and tissue culture techniques adapted to the mass production of clones by rooted cuttings and microcuttings of mature selected CPTs (Monteuuis 1995, Monteuuis et al 1995, 1998).

Selecting the CPTs

Teak CPTs are selected primarily on economically-important traits such as vigor, growth rate, bole shape, branchiness and wood quality, taking advantage of non-destructive assessment methods (Figure 2, Murillo and Badilla 2002, Goh et al 2007, Kokutse et al 2016). As a general rule, the larger the difference with the rest of the population, or the stronger the intensity of selection, the greater the commercial gain. Most of these traits are expressed, and thus can be assessed, only from developed or mature enough teak trees. Too many uncertainties are associated with juvenile trees or seedlings to allow for a reliable selection. In addition and for safer clonal deployment with regard to disease risks in particular, the CPTs must not be genetically too close. Next come the genotype X site interaction issues: what are the risks that these traits could be modified by planting site conditions? This will basically depend on the genotype capacity of the CPT, initially selected in a specific site, to adapt to other environments. Answering this question is the main purpose of properly set up clonal tests not withstanding the time, space, plant material and human resources required. The genetic quality and the diversity of the base populations, or more seldom the breeding populations, from which the CPTs are selected, are essential (Goh and Monteuuis 2005, Goh et al 2007), although attractive features of a few isolated CPTs can give rise to real success stories (Goh and Monteuuis 2012).

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Wood characteristics after 10 years of growth in Sabah conditions		Tropix reference [2]
Heartwood proportion	61 %	-
Basic density	520 kgm^{-3}	670 kgm^{-3}
Total shrinkage	5.9 %	-
Radial shrinkage	2.0 %	2.6 %
Tangential shrinkage	3.8 %	4.7 %
T/R Ratio (Nervosity)	1.9	1.8
Modulus of Elasticity	1370 Mpa	-
Modulus of Rupture	117 Mpa	98 MPa
Natural Durability [1]	Durable	Very Durable

Microsatellite locus name	Accession EMBL Database	Alleles
CIRAD1TeakA06	AJ968929	193 209
CIRAD1TeakB03	AJ968930	250 250
CIRAD1TeakF05	AJ968931	270 270
CIRAD1TeakG02	AJ968932	168 168
CIRAD1TeakH10	AJ968933	238 238
CIRAD2TeakB07	AJ968934	145 153
CIRAD2TeakC03	AJ968935	280 294
CIRAD3TeakA11	AJ968936	270 274
CIRAD3TeakB02	AJ968937	237 245
CIRAD3TeakD09	AJ968938	207 209
CIRAD3TeakF01	AJ968940	219 219
CIRAD4TeakD12	AJ968941	141 141
CIRAD4TeakH09	AJ968943	226 226

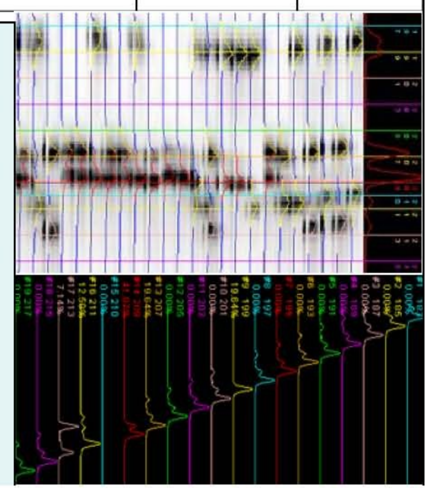

Figure 2. Refining the usual phenotypic selection of *in situ* CPTs by using non destructive methods of wood analysis and molecular markers

Vegetative propagation techniques

The requisites as well as the pros and cons of the efficient nursery and tissue culture techniques developed for mass clonally propagating by rooted cuttings and microcuttings the mature CPTs selected have been extensively developed (Monteuuis 1995, Monteuuis et al 1995, 1998, Monteuuis 2000, Monteuuis and Ugalde 2013). These aspects are also illustrated in Figures 3, 4 and 5. Moreover, the possibility to export tissue-cultured teak microshoots under importing country requirements to international destinations has rapidly opened up wide market prospects (Figure 6).

Origin, distribution and deployment of the clones planted

Asia and Oceania

Despite a limited impact at the domestic level, the company YSG Bioscape (previously known as YSG Biotech), a commercial subsidiary of the Sabah Foundation Group based in Sabah, East Malaysia, has played a major role in teak clone distribution all over the world.

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The main asset of this company is the overriding importance given from the start to the genetic aspects through the sound selection of mature CPTs based on phenotypic but also wood traits (Goh et al 2007, Goh and Monteuuis 2009). After 25 years of intensive activities supported and well-documented by numerous field trials and scientific publications, YSG Bioscape is still at the forefront of supplying worldwide a broad variety of teak clones, all derived from outstanding CPTs as well as genetically improved seeds from highly rich gene-pools (Goh and Monteuuis 2009).

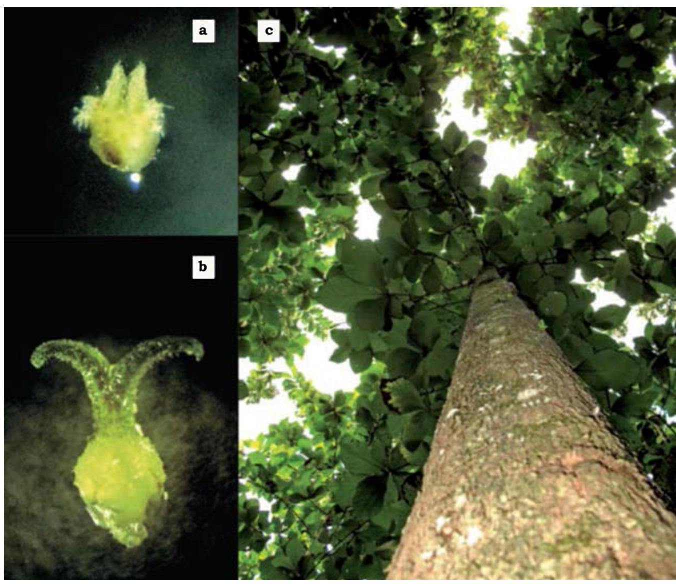

Figure 4. Clonal propagation of a mature selected teak using shoot apical meristem - 0.1 mm as overall size - (a) 3 weeks and (b) 8 weeks after introduction *in vitro* culture, then after 5 years in outdoor conditions in Sabah. *Note the very reduced lateral branching in absence of any pruning.*

Figure 6. Suitably packed YSG Biotech tissue-cultured clones can be successfully sent off to worldwide destinations

Figure 3. The fact that Teak can be easily mass clonally propagated by tissue culture or nursery methods from mature selected individuals in very cost efficient conditions is a strong support in favor of the clonal option

Figure 5. Meristem (100μm) culture-issued YSG Biotech clonal teak planted in Sabah under high rainfall and no marked dry season. In such conditions, these materials produce very few and thin lateral branches.

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In Indonesia, teak clonal plantations are rapidly expanding (Figure 7). YSG Bioscape Solomon Island clones (Goh and Monteuuis 2012) have been massively produced, sold and planted under various trade names, starting with Jati Jumbo in the early 2000s. On suitable sites, these clones planted in monoclonal blocks display very attractive and uniform phenotypic features (Figure 8). Average yield of at least 25 m^3/ha/yr can be expected for 1111 trees (3 x 3 m spacing)/ha after 5 yrs, at which time a 50% systematic thinning must be done for allowing the remaining 555 trees to develop further.

Figure 7. The 4 yr-old Super Teak JUN 1 intercropped with "garut" or arrow root (*Maranta arundinacea*) near Yogyakarta , Indonesia

Figure 8. Jati Jumbo/YSG Biotech clones 4 yrs after planting on steep slopes, southern Java. Maintenance was limited to weeding the first year, in absence of any pruning operation. The trees display the YSG Biotech TG1-8 characteristic features i.e. excellent straightness, reduced lateral branching and high leaf density accounting for increased photosynthesis and impressive growth rate

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In Australia, thousands of the "YSG Biotech TG1-8" teak clones (Goh and Monteuuis 2012) were actively planted in North-eastern Queensland during the early to mid 2000s. Unfortunately, due to changes in governmental policies, almost all the teak clonal plantations were later converted for other uses despite very encouraging behaviours in some places (Figure 9).

Figure 9. Representatives of the "YSG Biotech TG1-8" teak clones planted near Mossman, Northern Queensland, Australia. These clones are characterized by minimal lateral branching under high and evenly distributed rainfall regimes.

Latin America

Latin America is the region where teak clonal plantations have expanded most rapidly since the early 2000s (Ugalde 2013). This was primarily due to the superiority of the clonal material acquired from YSG Bioscape by a private Brazilian company known as Bioteca before it became Proteca that mass micropropagated teak by tissue culture (proteca.com.br, Goh and Monteuuis 2012, Ugalde 2013).Since then, Proteca had expanded its marketing activities to the whole of Latin America thanks to the possibility of exporting tissue cultured plants to any foreign countries in the absence of phytosanitary restrictions. Shipping time is the main constraint for tissue cultured plants. In this respect, Proteca had easier and safer access to Latin American buyers than YSG Biotech located at a far greater distance. Several millions plantlets, consisting mainly of YSG Biotech clones, have to date been produced by Proteca which has also adopted nursery techniques for "on the spot" mass clonal production of minicuttings from juvenile or in vitro-rejuvenated genotypes (Ugalde 2013, proteca.com.br). This option, initially developed in Costa Rica (Murillo et al 2013) and whose pros and cons have been detailed elsewhere (Monteuuis and Ugalde 2013), has been used extensively for mass producing at the domestic level clones selected locally or imported from abroad. This has resulted in the large and uncontrolled dissemination of superior teak clones in many Latin American countries with special mention for the highly morphologically distinguishable YSG Biotech clones after they had been introduced directly from Sabah, or via Proteca.

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Since its inception in year 2000, Genfores, a Costa Rican tree improvement and gene conservation cooperative, has actively contributed to teak breeding and clone selection in close collaboration with private companies like Precious Woods, now Novel Teak, Barca, and PanAmerican Woods (Murillo et al 2004). Initiated at the national level where 60% of the teak plants produced in Costa Rica nowadays are clones (Murillo personal communication), Genfores expertise has benefitted an increasing number of Latin American countries including Brazil, Columbia (Espitia et al 2011), Ecuador, Nicaragua, Panama. For newly selected clones which have not been soundly field tested in operational planting conditions yet, GenFores recommends planting a sufficient number of these "candidate" clones in mixture, whereas more certified clones can be deployed in monoclonal blocks.

Teak clonal plantations are also rapidly expanding in other Central American countries like Mexico, and Guatemala but unfortunately little is known regarding the genetic background of the clones that are massively planted there. However, the phenotypic characteristics of most of these materials suggest that they are coming from YSG Bioscape which has sent tissue cultured teak clones to different companies in each of these countries.

Africa

Kilombero Valley Teak Company, KVTC for short, located in Tanzania, currently owns the biggest private teak plantation in the whole continent. The company first started planting clones 12 years ago with the YSG Bioscape TG1-8 (Goh and Monteuuis 2012) and these were later enriched with locally selected materials. Out of the 8000 ha currently planted with teak, 300 ha are clonal plantations encompassing clonal tests and commercial plantations of clones in mixture. The origins of the clones are YSG Biotech (50%), KVTC own selections (40%) and others (10%). All the different clones are individually propagated in-house by rooted cuttings (up to 100,000 per year) allowing a total control of the genetic composition of the clonal material deployed.

In addition 100 ha of teak clonal plantations consisting exclusively of a mixture of the same 8 YSG Biotech clones have been established by PFM in Gabon, Central Africa, under average rainfall of 2,500 mm/yr with a 4 month-long dry season. A clonal test comprising 32 YSG Biotech clones supplied as microcuttings has also been set up within the same project, to be ultimately converted into a CSO.

In West Africa, large scale clonal propagation by rooted cuttings from juvenile CSO seedlings took place in SODEFOR, Ivory Coast during the period, 1995-2005 (Martin et al 2000), before applying the technology developed in Sabah (Monteuuis et al 1995) for mature selected CPTs. This technology was also proven to be successful in FORIG, Ghana, and more recently in Togo where all the 25 Plus trees selected could be cloned (Kokutse et al 2016). At SoGB, Grand Béréby, Ivory Coast, 24 YSG Biotech clones have also been established within a clonal test that can be again, ultimately utilized as a CSO after proper thinning. Further, the TG1-8 clones have been planted between rubber tree rows as a pilot agroforestry plantation.

Critical Issues and recommendations

Genetic background of the planted clones

One major concern of teak clonal forestry is the lack or loss of information on the genetic origin of the clones that have been mass propagated and planted, due to various reasons (Monteuuis and Goh 2017). Whatever the origin, the greater the number of propagation cycles and intermediaries between the CPTs *in situ* and the operational planting, the higher the risks of mixing and losing the initial clones, particularly those that have been propagated or supplied as a mixture, in bulk (Monteuuis 2000, Monteuuis and Ugalde 2013). The threat is a rapid impoverishment of the genetic diversity of the clones deployed for large scale planting, exposing them to greater risks of pest and disease problems, and ultimately of a too high uniformity of the end-use products. The dramatic consequences of establishing large scale plantations with too few clones should not be minimized. This is why maintaining wise genetic improvement programs aiming at producing new clones is crucial (Monteuuis and Goh 2005).

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The sound utilization of adapted DNA markers can be very helpful for overcoming genetic origin and relatedness issues (Figure 2, Monteuuis and Ugalde 2013), but unfortunately, these technologies are currently still underused at the operational level.

Planting site

Selected teak clones are more expensive than seedlings and should therefore be planted on suitable sites. Precipitations appear to be of great importance for ensuring good post-planting survival first, then for promoting rapid growth. As indicative figures, 244 m^3/ha and 331 m^3/ha were recorded at an experimental scale in Sabah for certain clones 5 and 7 yrs after planting at 1250 and 1111 trees/ha, that corresponds to 48.8 m^3/ha/yr and 47.3 m^3/ha/yr, respectively (Goh et al 2013, Monteuuis and Goh 2015). This illustrates that well drained planting sites exposed to high and well distributed rainfall regimes – 2000 mm/yr or more –are recommended to get the earliest returns on investments for superior teak clones. It can logically be assumed that in absence of hydric constraints, the more exposed top apical meristem of the main stem, will keep on growing up, thereby increasing bole length and maintaining the apical dominance. This prevents the elongation of the underneath axillary buds hence the formation of lateral branches and of the associated nodes that depreciate wood value and as such need to be pruned (Figure 10). But these pruning operations are expensive, require substantial time and manpower. Furthermore they must be carried out at the right stage of branch development: too early will affect photosynthesis capacity, hence tree growth, too late the nodes will be too big. The possibility to avoid pruning by planting suitable teak clones under wet conditions must therefore be considered as a real advantage compared to sites with a marked dry season (Figures 4, 5, 7, 8 and 9).

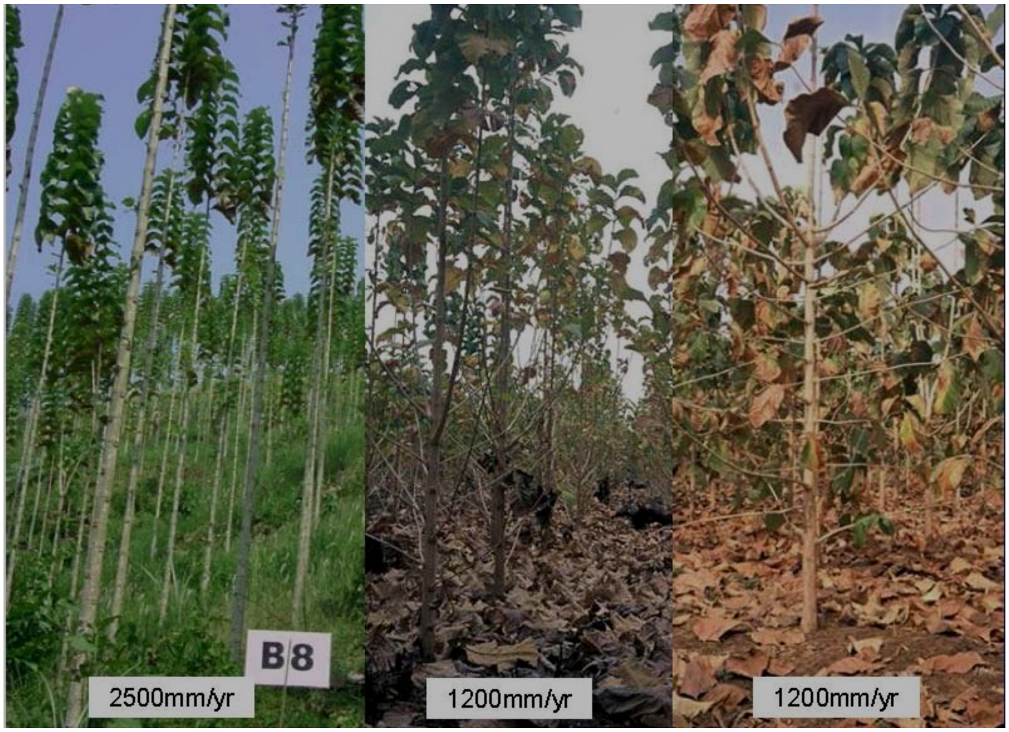

Figure 10. 2 yr-old representatives of a YSG Biotech clone under different rainfall regimes and soil conditions (middle and right)

This latter has been for a long time regarded as a requisite for the formation of good quality teak wood. But *Tectona grandis* has a wide range of natural distribution encompassing highly humid locations without dry season where teak trees grow much faster and produce higher yield of premium quality wood than in drier conditions. So, the fact that the species can overall stand long period of drought does not necessary imply that this is a specific requirement. Further and contrary to another general belief, soil acidity has apparently not a determining influence on teak development, as observed for instance in Sabah where the species thrived on pH ranging between 4 and 5 (Chaix et al 2011, Monteuuis et al 2011, Goh et al 2013) and in Chiapas, Mexico (AGSA, personal communication).

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Clone deployment

Teak clones can be used for establishing monospecific plantations, but also to be intercropped with other species of different kind within agroforestry systems, or even for silvopastoralism (Ugalde 2013).

Within monospecific plantations, clones can be mixed with seedlings or planted in mixture as a bulk with the purpose of minimizing the negative impact of unadapted genotypes as compared to monoclonal blocks which are more uniform, for better or worse. Such mixtures can be warranted for clones that have not been tested in the conditions of large scale deployment prior to their utilization owing to time, space and cost constrains. In addition, intercropping clones with seedlings diminishes planting stock cost, the latter being cheaper than cutting or microcutting-derived clonal material. On the other hand, selected clones, contrary to seedlings, do not require intensive thinning operations for removing the poorer trees and thus, can be planted at a lower density, compensating at least to some extent, for their higher cost.

Silvicultural practices consisting in harvesting several times from the same stump, taking advantage of teak specific coppicing ability for avoiding replanting have been undertaken, but were apparently not as successful as expected (Martin et al 2000). Similarly to industrial eucalyptus plantations, the best way of deploying teak clones proven to be adapted to the local conditions is in the form of monoclonal blocks established according to a space-time mosaic design. The objective is to avoid overly large areas planted with genetically- related clones that are more susceptible to potential pest and disease damages. The size of these monoclonal blocks will depend on the total number of clones, their genetic relatedness, their individual phenotypic characteristics, the rotation length and the total area to be planted.

Teak clones can also be selected on trunk shape and crown form criteria to be intercropped with other fruit or vegetable species within highly productive agroforestry system, benefiting from the culture conditions provided to the other crops for a higher return than could be obtained from seed-derived trees.

Teak clones can be thus associated with oil palm trees, rubber trees, coffees and bananas (Figures 11 and 12).

Figure 11. Intercropping teak clones with banana and coffee in French Guiana

Figure 12. Intercropping teak clones with oil palm

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Lastly, owing to their higher vigor, stronger root systems and attractive phenotypic features teak clones have been observed to be more suitable and economically profitable for silvopasture than teak seedlings (Figure 13, Ugalde 2013).

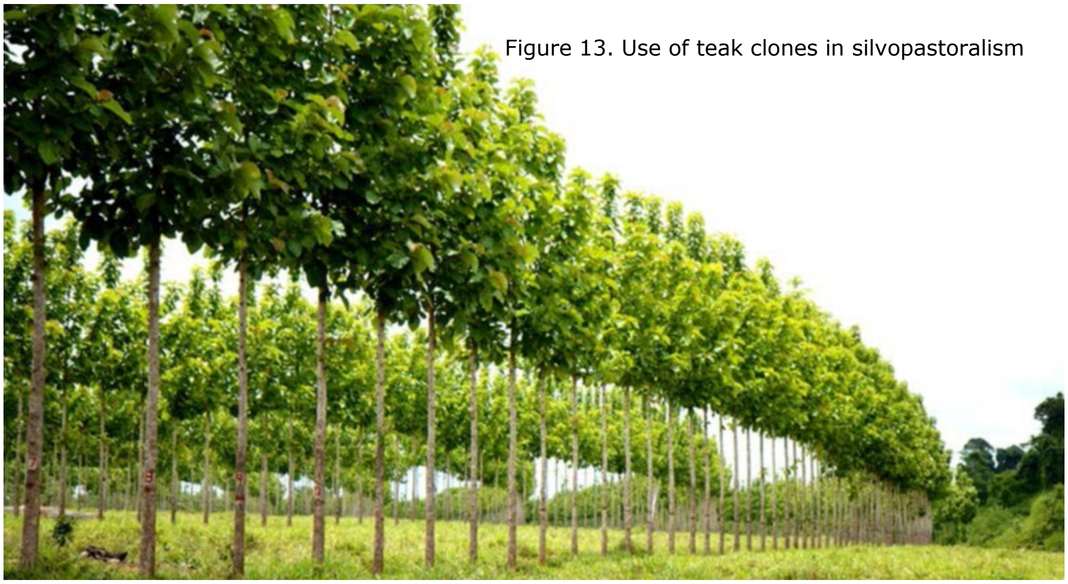

Figure 13. Use of teak clones in silvopastoralism

Conclusion

From the work initiated by YSG Bioscape jointly with Cirad-Forêt more than 2 decades ago, it is now established that clonal forestry can overcome most of the limitations associated with seedling-derived plantations of teak, the most prized and planted high value timber species worldwide. Thanks to the possibility of establishing fast growing and uniform teak plantations of enhanced yields, high wood quality and commercial value on short rotations, the clonal option seems the best way to maximize returns on investments. However, teak clonal forestry success remains strongly dependent on a few major conditions which are:

i) the wise and reliable selection of outstanding CPTs for traits of major economical importance, the more the better, devoting an overriding importance to wood characteristics for such a highly prized timber;
ii) the use of efficient and cost-effective methods for the true-to-type mass multiplication of selected CPTs ;
iii) the sound deployment of the clones produced on suitable planting sites.

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